A comparison of clinic based dosimeters based on silica optical fibre and plastic optical fibre for *in-vivo* dosimetry

Lingxia Chen*[a], Sinead O'Keeffe[a], Peter Woulfe[a,b], Elfed Lewis[a]
[a]Optical Fibre Sensors Research Centre (OFSRC), Electronic & Computer Engineering Dept., University of Limerick, Ireland, V94 T9PX; [b]Dept. of Radiotherapy Physics, Galway Clinic, Galway, Ireland, H91 HHT0

ABSTRACT

Four sensors based on silica optical fibre and plastic optical fibre for clinical *in-vivo* dosimetry have been fabricated and tested on site at Galway Clinic. The initial comparison results have been attained for the four sensors when they have been irradiated with beam energies of 6 MV and 15 MV at different dose rates using a modern clinical linear accelerator (Linac) as the radiation source. According to the experimental test results, the sensors based on silica optical fibre exhibit greater sensitivity to the incident radiation beam than the sensors based on plastic optical fibre when they are exposed to identical irradiation conditions. The output intensity from the sensor based on silica fibre is 5 times higher than the sensor based on plastic optical fibre.

Keywords: Dosimeter, optical fibre sensor, silica optical fibre, plastic optical fibre, scintillation material

1. INTRODUCTION

Radiation dosimetry has a significant role to play in modern radiation therapy including brachytherapy and External Beam Radiotherapy (EBRT). It is extensively used to maintain radiation therapy Quality Assurance (QA) and to minimize the damage to surrounding healthy tissues when the target tumour is exposed to radiotherapy treatment. Therefore, it is crucial to design and fabricate a reliable, precise, repeatable, real-time dosimetry system that can be used in a wide range of radiation oncology applications. In the past few decades, measurement has been performed by several dosimetry systems based on a wide range of technologies, including ionization chamber (IC)[1], metal oxide semiconductor field effect transistors (MOSFETs)[2], thermo-luminescence dosimeters (TLDs)[3], silicon diodes[4], radio-chromic film[5], electronic portable imaging devices[6], diamond detectors[7] and optical fibre sensors[8], and these continue to be investigated by the research groups from all over the world.

To date, dosimeters based on optical fibre techniques comprising scintillator materials and plastic optical fibres (POFs) have proved to be a popular selection for use in monitoring dose in the clinical radiotherapy setting[9]. Plastic has gained popularity as a material due to its potential biological compatibility and other unique advantages, such as an effective atomic weight (Z_{eff}), which is close to that of human tissue (and water), good spatial and temporal resolution i.e. the fibres can be made with very small diameter (about 0.25 mm), immunity to external electromagnetic interference, and potential low cost[10]. However, compared with plastic optical fibre (POF), silica optical fibre (SOF) has some additional advantages over POF in low signal attenuation, even smaller overall diameters (in the case of single mode), lower cost per metre, low Kerr nonlinearity, and potentially higher damage threshold from external ionizing radiation.

In this paper, both silica optical fibre (SOF) and plastic optical fibre (POF) are investigated as the optical waveguide material used in the dosimeters. Four dosimeter sensors have been fabricated and tested on site at the Galway Clinic, Ireland, using a modern linear accelerator (Linac: Siemens Oncor Avant Garde, with 160 Multi-Leaf Collimators and IGRT (Image Guided Radiotherapy)) as the radiation source. Of the four sensors, two are based on silica fiber (FP200URT, from Thorlabs Ltd) which are encapsulated in a 1.2 mm diameter polypropylene tube and a borosilicate glass capillary of 0.7 mm diameter; and the two other sensors are based on the plastic fibre (DC-265-10, manufactured by AsahiKASEI), placed separately within the identical polypropylene tube and a borosilicate capillary of 0.3 mm diameter. Experimental test results obtained on site at Galway Clinic for all four sensors are presented and an initial analysis is performed.

*Lingxia.chen@ul.ie; phone 00353899802911

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2. EXPERIMENTAL TEST SET UP

The sensing segments of the four sensors have the same structure, which are shown schematically and photographically in Fig. 1. The scintillation powder, terbium doped gadolinium oxysulfide ($Gd_2O_2S:Tb^{3+}$; type UKL65/F-R1 from Phosphor Technologies Ltd, UK) was fully contained within the polypropylene tube or the borosilicate capillary, one end of which was sealed by silicone and the fibre (SOF or POF) inserted into the opposite end of the tube. A multi-pixel photon counter (MPPC), (Hamamatsu MPPC C11208-01) Avalanche Photodiode (APD) array detector that is thermoelectrically cooled (to allow for low light intensity detection) was located at the distal end of the optical fibre at a distance of about 20m allowing it to be located in the control room outside of the radiation delivery suite. When the radiation source is turned on, the scintillation powder under the irradiation, emits visible green light (544 nm) through fluorescence.

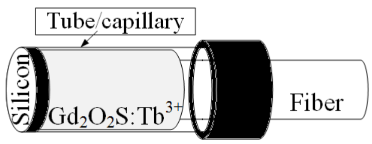

Fig. 1 (a) The schematic diagram of sensor

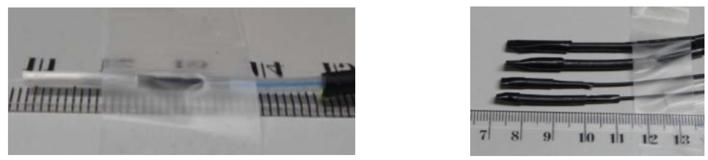
Fig. 1 (b) The pictures of the entity of the sensing element

The specific components comprising of the four types of sensors, which are SOF, POF, polypropylene tube and borosilicate capillary are listed in the Table 1. The four sensors are labelled SOF1, SOF2, POF1 and POF2, separately. The dimensions of the sensors are also noted in Table 1. All tests were conducted using the Linac setting to deliver a radiation dose of 100 MU (Monitor Unit which approximately equates to 1 cGy). Due to operational limitations of the Linac, there were only two dose rates available for each of the two beam energy values (6 MV and 15 MV) used in this investigation; when the Linac was used with the 6 MV beam energy, the available dose rates were 50 MU/min and 300 MU/min, and when the Linac was used with the 15 MV beam energy, the available dose rates are 50 MU/min and 500 MU/min. In all cases a standard set up for beam delivery was provided i.e. Source to Surface Distance (SSD) of 100 cm, field width 10 cm × 10 cm and the sensor was mounted on the table (Depth below surface = 0).

Table 1. The parameters of the components of the sensors

Label	**Fibre Specification**			**Scintillation Powder Holder**		**Sensing* Segment Length / mm**
	Core Dia.	***Cladding Dia.***	***Type of Fibre***	**Material**	**Inner Dia./ mm**	
SOF1	200 μm	225 μm	Silica Optical Fibre (SOF)	polypropylene	1.0	4
SOF2				borosilicate	0.7	4
POF1	260 μm	265 μm	Plastic Optical Fibre (POF)	polypropylene	1.0	4
POF2				borosilicate	0.3	4

* represents the length along the axis of the optical fibre of the scintillation powder in the holder.

3. RESULTS

3.1 Results from the POF based sensors

Fig. 2 includes results from the two sensors based on the POF (POF1 and POF2) with different scintillation powder holders under different radiation conditions. Fig. 2 shows the real-time intensity of the output signal from POF1 and POF2, when they were irradiated with 50 MU/min dose rate at the two different beam energy values of 6 MV and 15 MV. The black solid line represents the signal from POF1 when the energy of the radiation was 6 MV, and the grey solid line represents the signal from POF1, when the beam energy was 15 MV; the red dashed line represents the signal from POF2 when the energy of the radiation was 6 MV, and the blue short dashed line represents the signal from POF2, when the energy of the radiation was 15 MV. The results of Fig. 2 clearly demonstrate that both POF sensors produce a higher output (intensity) signal when the sensors are irradiated using the 6 MV beam energy than the 15 MV beam energy, which is caused by the energy dependence of the phosphor due to the high Z_{eff} components present[11]. The quantitative comparison based on the output intensity ratio for the set of POF based sensors, POF1 versus POF2 with different irradiation conditions is determined. The average ratio of the intensity of the output signals from POF1 over POF2 at different irradiation conditions is 9.88. This is relative with the quantity of scintillation powder as the diameter of polypropylene tube of POF1 is about as 3.3 times bigger as the borosilicate capillary of POF2's.

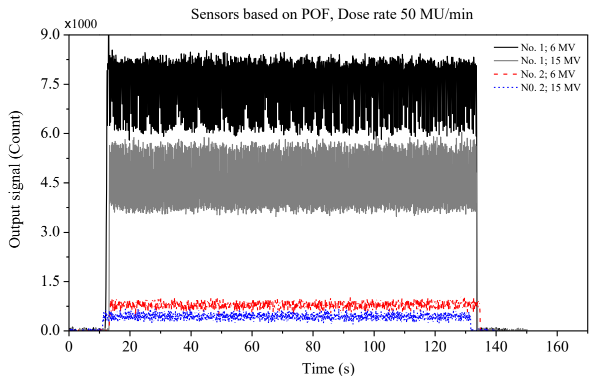

Fig. 2 The real-time intensity of the output signal from POF1 and POF2 when they are irradiated with a dose rate of 50 MU/min for beam energy values of 6 MV and 15 MV

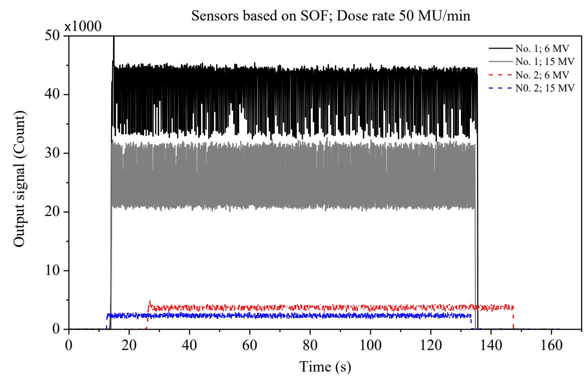

Fig. 3 The real-time intensity of the output signal from SOF1 and SOF2 when they are irradiated with a dose rate of 50 MU/min for beam energy values of 6 MV and 15 MV

3.2 Results from the SOF based sensors

The sensors based on the SOF with polypropylene tube and borosilicate capillary (SOF1 and SOF2) have been tested under the conditions identical to those of the sensors based on POF, as described in Section 3.1. Fig. 3 shows the real-time intensity of the output signal from SOF1 and SOF2 for a 50 MU/min dose rate, with beam energy values of 6 MV and 15 MV (Fig 3). It is notable that, the diameter of the borosilicate capillary is only 0.3 mm in the case of the POF based sensors (POF2) as opposed to 0.7 mm in the case of the equivalent sensor in the SOF case (SOF2). Therefore, the ratio of the diameters of polypropylene tube over borosilicate capillary is 1.43, and so the ratio of the intensity of the output signal from POF1 over POF2 is expected to be approximately 2. However, in this particular case, the ratio of the intensity of the output signal from SOF1 over SOF2 is found to be 11.02, which is not proportional to the quantity of scintillation material used. This may be caused by signal loss at the end of SOF connected with the scintillation material, and needs to be verified with the further work.

3.3 Comparison between the sensors based on SOF and POF

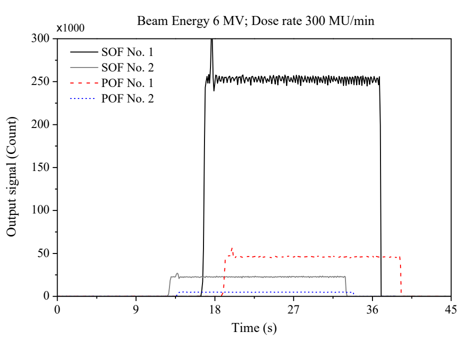

Fig. 4 (a) The real-time intensity of the output signal from the four sensors when they are under the radiation with 6 MV energy and 300 MU/min dose rate

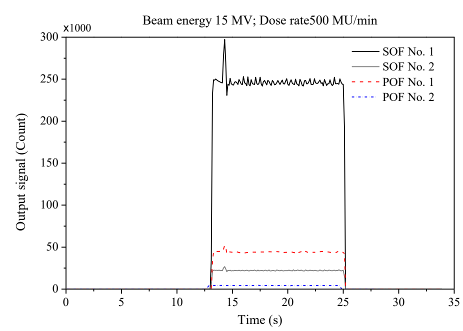

Fig. 4 (b) The real-time intensity of the output signal from the four sensors when they are under the radiation with 15 MV energy and 50 MU/min dose rate

In this section, comparisons are made of the output signals of the sensors based on SOF and POF under the different irradiation conditions. These are shown in Fig. 4. In this case the time response of all four sensors is shown for identical conditions. The irradiation conditions are for 6 MV beam energy and 300 MU/min dose rate (Fig. 4 (a)), and 15 MV energy and 500 MU/min dose rate (Fig. 4 (b)), respectively. For both sets of irradiation conditions, the same order of the output signal intensity from high to low is evident, which is SOF1, POF1, SOF2 and POF2. The output intensity from the SOF based sensors is approximately 5 times higher than that of the POF based sensors. The greater intensity in the case of the SOF sensor compared to the POF sensor is primarily attributable to the low attenuation of the SOF when the fluorescent light signal is travelling in the silica optical fibre (the attenuation of SOF is approximately 25 dB/km and the attenuation of POF is approximately 120 dB/km, which is approximately 5 times higher than the SOF's).

4. CONCLUSION

Four sensors two each based on SOF and POF mounted inside a polypropylene tube and borosilicate capillary holder have been tested using a clinical Linac with different beam energy values and varying the dose rate. Both SOF based sensors and POF based sensors have greater intensity because of the differences in the geometrical launch conditions for the fluorescent light signal from the scintillation material as it is coupled into the receiving fibre. The sensors based on SOF exhibit greater sensitivity to the incident radiation beam than the sensors based on POF when they are exposed identical irradiation conditions, the output intensity from the sensor based on SOF being 5 times higher than from the sensor based on POF. The authors believe that the greater intensity in the case of the SOF sensor compared to the POF sensor is primarily attributable to the low attenuation of the SOF. However, the results of the current investigation have shown that all the sensors which have been fabricated exhibit an energy dependency, which should be minimized or ideally completely eliminated. Future work is focused on testing new scintillation materials, with a low Z_{eff} value close to that of water which has low dependence on the radiation source energy.

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